# Phase 2 of the Energy Storage Proceeding

Possible Models to Assess Cost Effectiveness

September 24, 2012

# DNV - Integrity at the core



- Independent foundation established in 1864

- Self-owned with no shareholders

- Stakeholders are represented in our governing bodies and committees

- We use profits to continuously develop our people and our research and innovation

# DNV KEMA - Energy & Sustainability



- DNV KEMA Energy & Sustainability offers innovative solutions to customers across the energy value chain, ensuring reliable, efficient and sustainable energy supply, now and in the future.

- 2300+ experts across all continents

- KEMA and DNV combined: a heritage of nearly 150 years

- US Headquarters in Burlington, MA

- Offices and agents in over 30 countries around the globe

- DNV Global:  300 Offices, 100 Countries, 10,400 Employees

# Contents

# DNV KEMA Analysis Tools for Storage
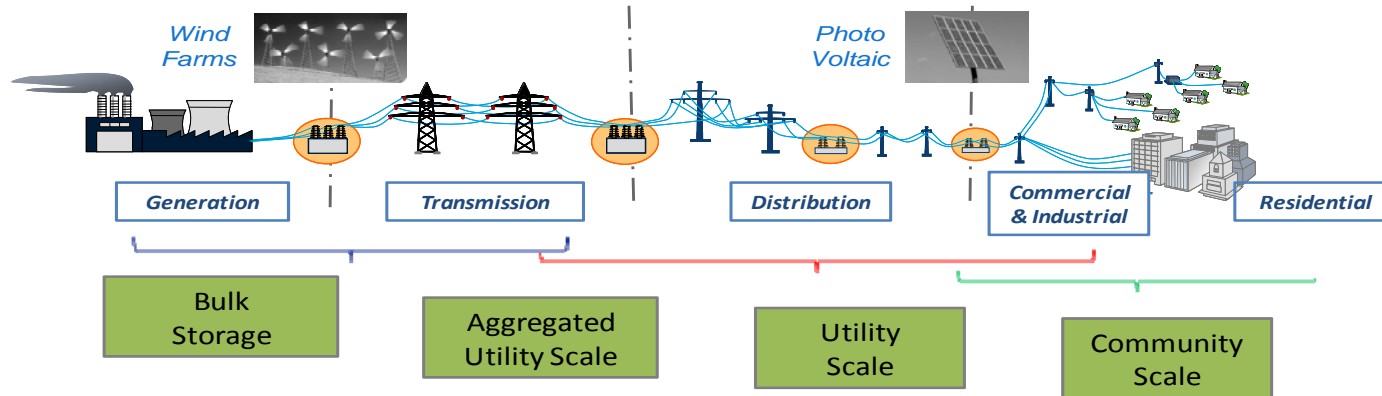


- **KEMA Tools are targeted to assess storage at each area of the grid**
  - *ES Select*:  Targeted to weigh various technologies of storage against specific applications and incorporating "bundling features" into the analysis – used at all levels of the grid
  - *Distribution Valuation Tool*:  Designed to assess benefits of storage applications at the distribution level through simulated circuit analysis – focused on distribution
  - *KERMT Model*:  Real time Simulation model to assess storage at the whole sale, generation level – focuses on renewable integration and regulation
  - *Peaker Model:*  Tool to assess storage as a peaker substitute

- **Slides focus on ES-Select, Distribution Valuation Tool, and KERMIT Model**
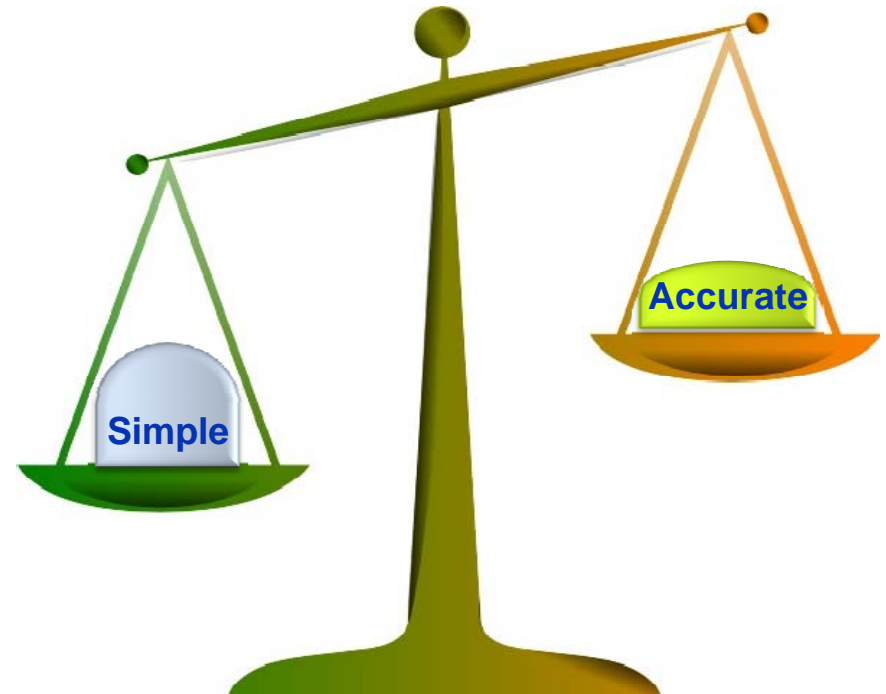
# Contents

# What Does ES-Select Provide?

**Why Build This Model?**

- Prioritized list of **feasible energy storage technology options** for targeted applications

- **Cost-performance comparison** of feasible storage technologies

- **10-year technical market potential** of applications in North America

- **Present Value benefits over 10-years** for applications in North America
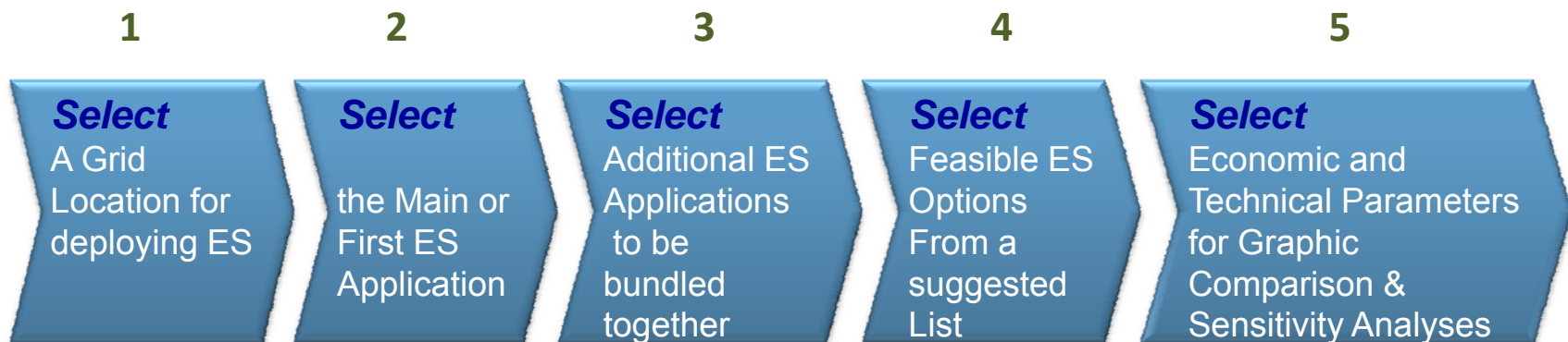
**Where to Find the Public Version of This Model?**

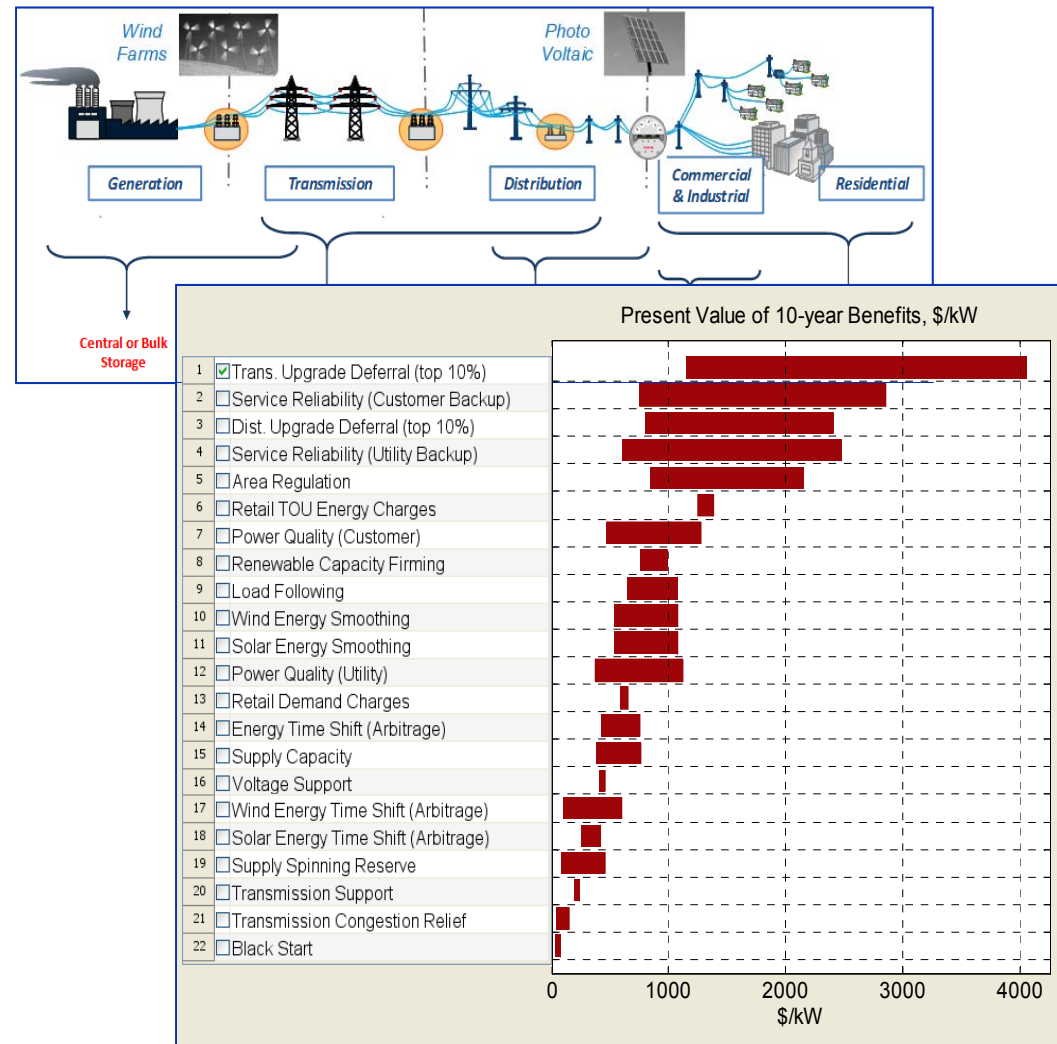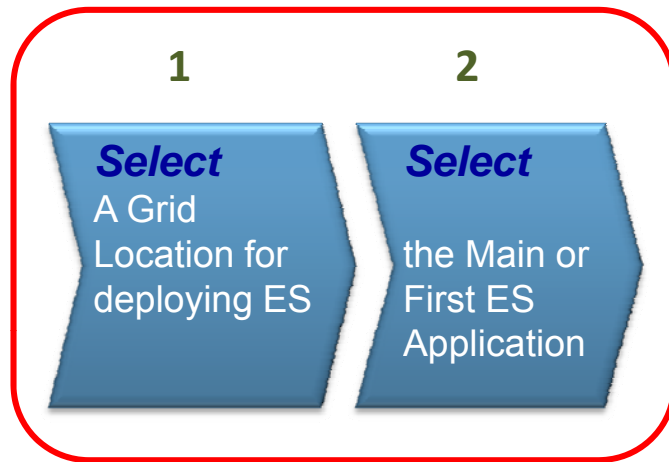http://www.sandia.gov/ess/esselect.html

# ES-Select Overview

In a step-by-step interactive manner, ES-Select identifies and compares the feasible Energy Storage (ES) options for different grid applications

1. Asks: Location
2. Asks: Main Application
3. Option for: Additional Applications
4. Offers: Feasible ES Options
5. Compares the feasible ES Options

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| *Select* A Grid Location for deploying ES | *Select* the Main or First ES Application | *Select* Additional ES Applications to be bundled together | *Select* Feasible ES Options From a suggested List | *Select* Economic and Technical Parameters for Graphic Comparison & Sensitivity Analyses |

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# First Two Steps – Where & What Application?

## 1
**Select**
A Grid Location for deploying ES

## 2
**Select**
the Main or First ES Application



Wind Farms

Photo Voltaic

Generation    Transmission    Distribution    Commercial & Industrial    Residential

Central or Bulk Storage

### Present Value of 10-year Benefits, $/kW

| # | Application | |
|---|---|---|
| 1 | ☑ Trans. Upgrade Deferral (top 10%) | |
| 2 | ☐ Service Reliability (Customer Backup) | |
| 3 | ☐ Dist. Upgrade Deferral (top 10%) | |
| 4 | ☐ Service Reliability (Utility Backup) | |
| 5 | ☐ Area Regulation | |
| 6 | ☐ Retail TOU Energy Charges | |
| 7 | ☐ Power Quality (Customer) | |
| 8 | ☐ Renewable Capacity Firming | |
| 9 | ☐ Load Following | |
| 10 | ☐ Wind Energy Smoothing | |
| 11 | ☐ Solar Energy Smoothing | |
| 12 | ☐ Power Quality (Utility) | |
| 13 | ☐ Retail Demand Charges | |
| 14 | ☐ Energy Time Shift (Arbitrage) | |
| 15 | ☐ Supply Capacity | |
| 16 | ☐ Voltage Support | |
| 17 | ☐ Wind Energy Time Shift (Arbitrage) | |
| 18 | ☐ Solar Energy Time Shift (Arbitrage) | |
| 19 | ☐ Supply Spinning Reserve | |
| 20 | ☐ Transmission Support | |
| 21 | ☐ Transmission Congestion Relief | |
| 22 | ☐ Black Start | |

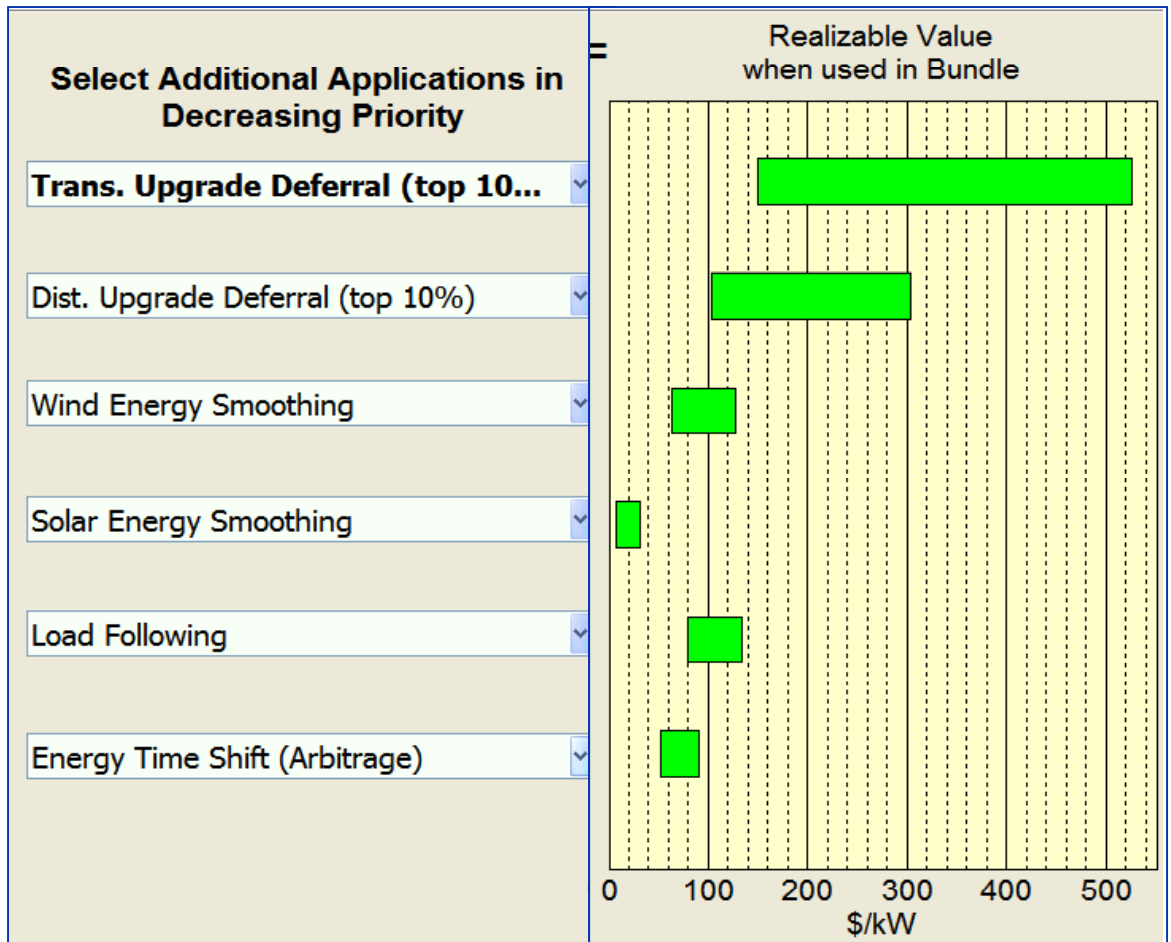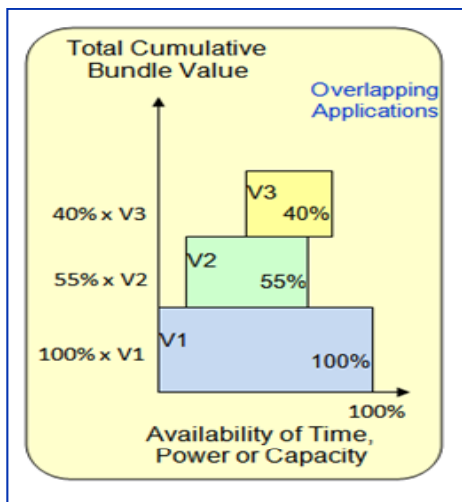0    1000    2000    3000    4000
$/kW

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# Next - Selection of Additional Applications

ES-Select identifies the next highest-value application, if desired.

**3**

**Select** Additional ES Applications to be bundled together

Total Cumulative Bundle Value

Overlapping Applications

40% x V3 — V3 40%

55% x V2 — V2 55%

100% x V1 — V1 100%

100%

Availability of Time, Power or Capacity

**Select Additional Applications in Decreasing Priority**

Trans. Upgrade Deferral (top 10...

Dist. Upgrade Deferral (top 10%)

Wind Energy Smoothing

Solar Energy Smoothing

Load Following

Energy Time Shift (Arbitrage)

Realizable Value when used in Bundle

0    100    200    300    400    500
$/kW

# Output – A List of Feasible Storage Options

## ES-Select Sorts Suggested ES options by their "feasibility Score"

**4**

**Select**
Feasible ES
Options
From a
suggested
List
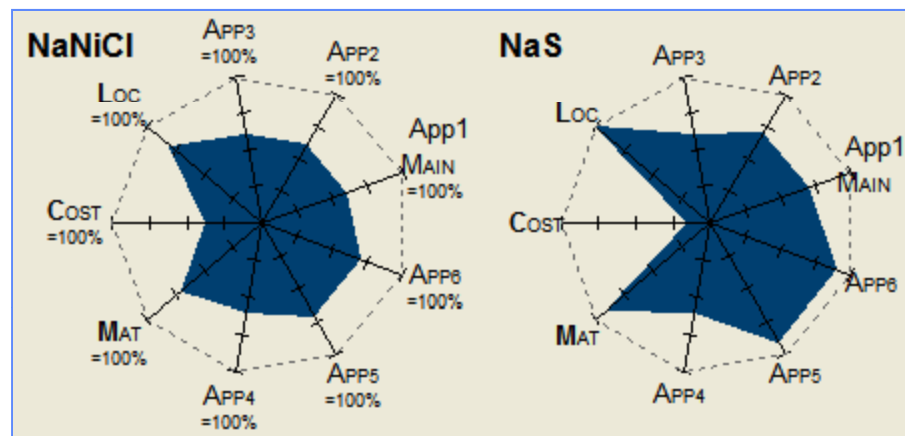


| 1 | ☑ **Sodium Nickel Chloride** | NaNiCl | 60% |
| 2 | ☑ **Sodium Sulfur** | NaS | 56% |
| 3 | ☑ **Compressed-Air ES, cavern** | CAES-c | 54% |
| 4 | ☑ Zinc Bromide | ZnBr | 54% |
| 5 | ☑ Ni batt. (NiCd, NiZn, NiMH) | Ni-batt | 51% |
| 6 | ☑ Advanced Lead Acid | LA-adv | 51% |
| 7 | ☐ Compressed-Air ES, small | CAES-s | 46% |
| 8 | ☐ Lithium Ion - High Energy | LIB-e | 42% |
| 9 | ☐ Vanadium Redox Battery | V-Redox | 31% |



Score for Meeting Location Requirements
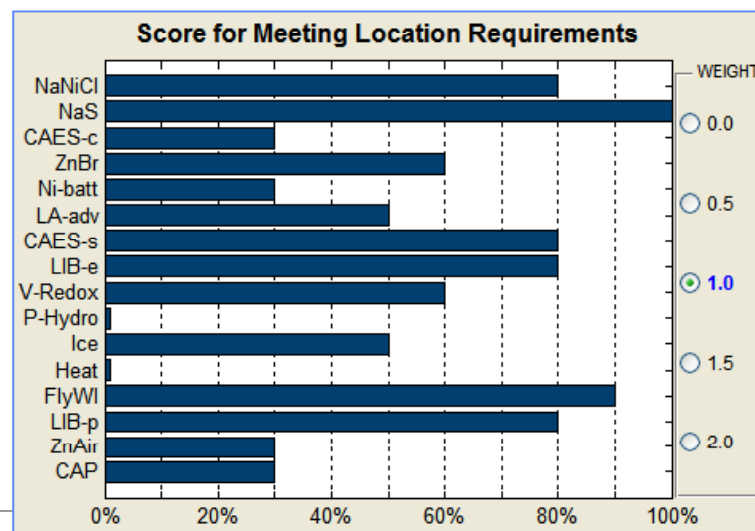
# Last- Apples-to-Apples Comparison of Options

**5**

**Select**
Economic and
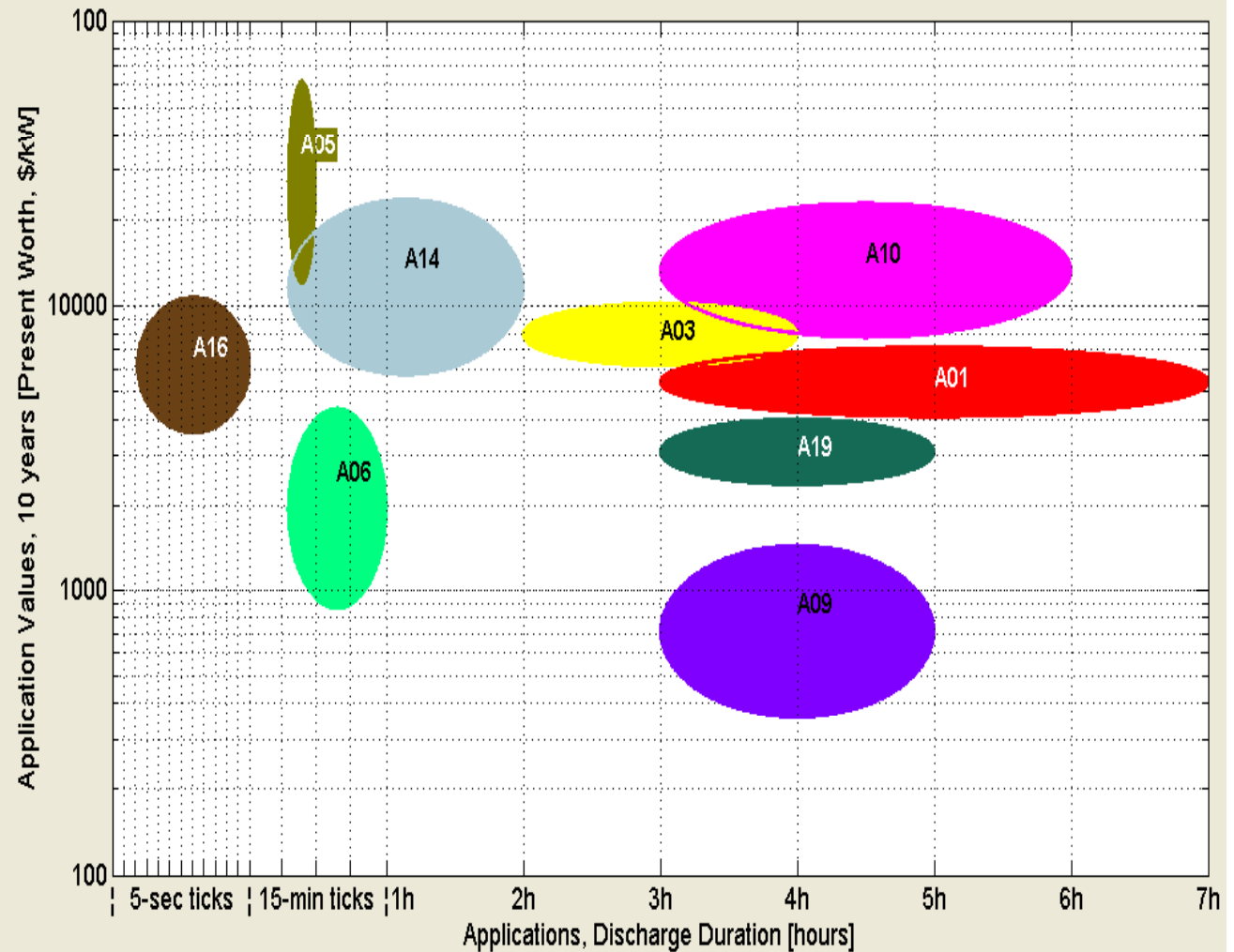Technical Parameters
for Graphic Comparison
& Sensitivity Analyses
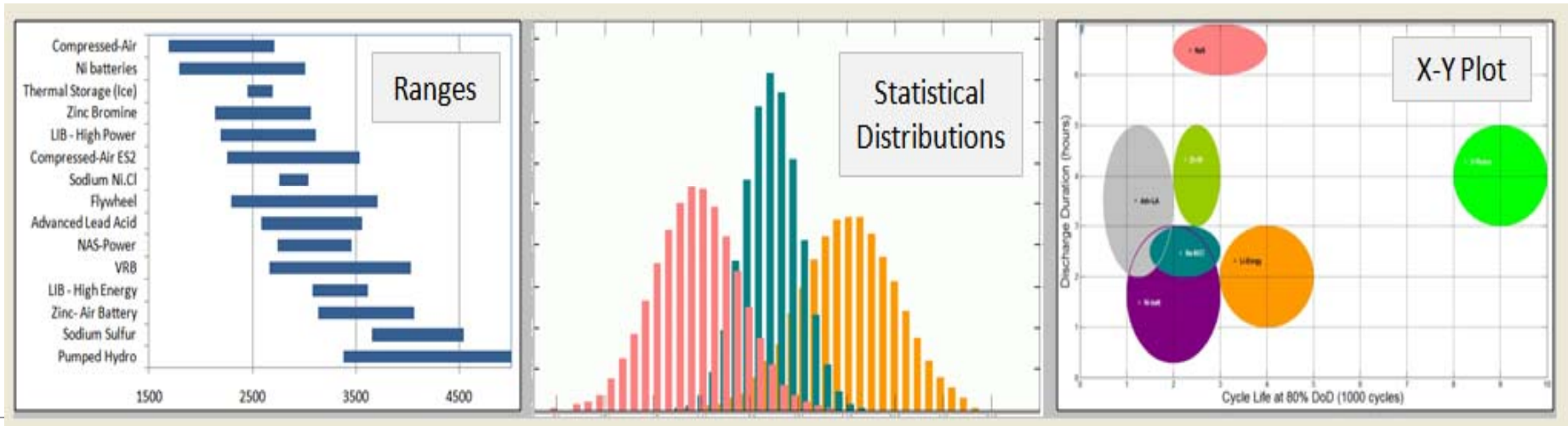
# Sample Outputs – Bubble Charts
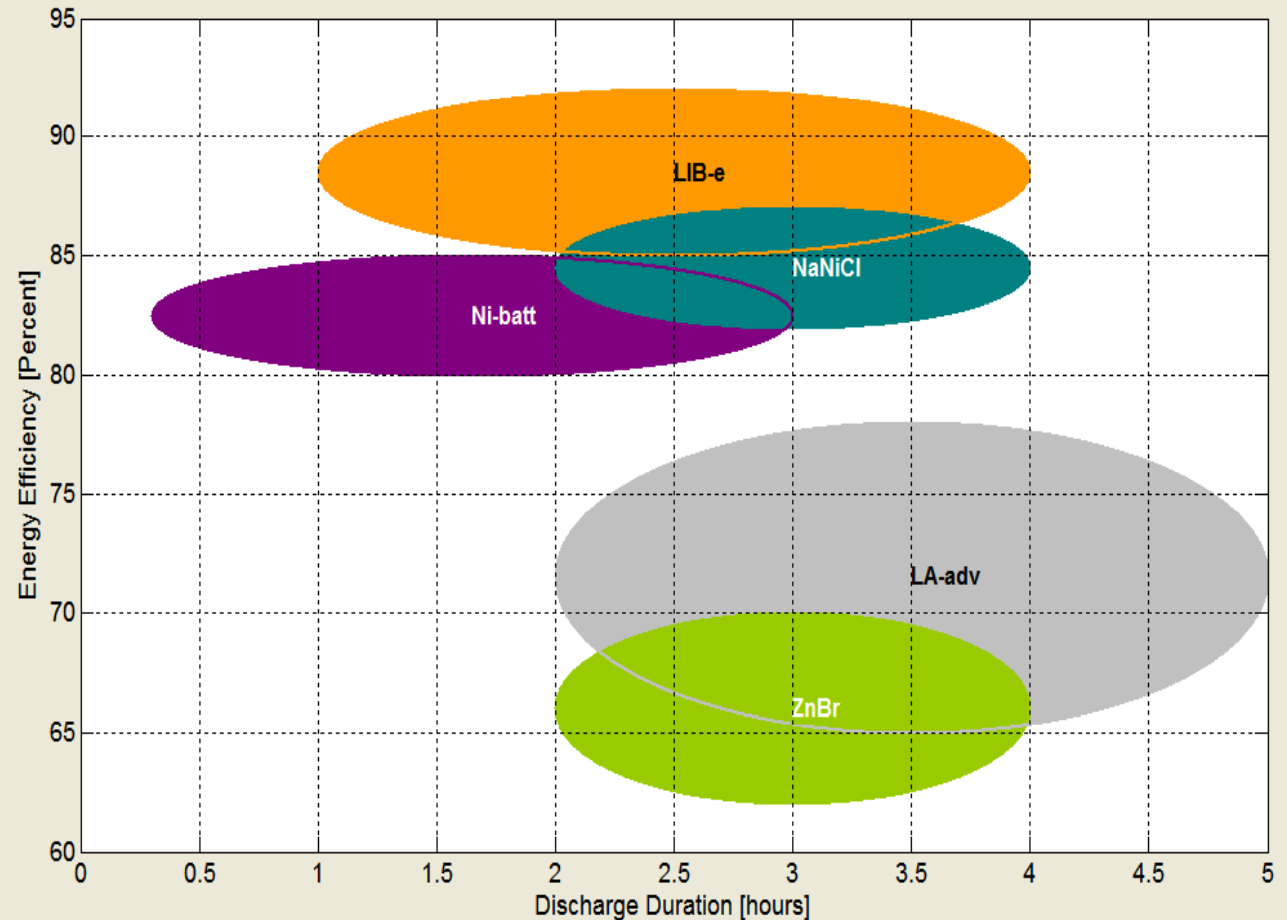
# Sample Outputs – Special Charts

# PNNL Support

- The total value of combined applications are "estimated"

- PNNL is supporting a study to improve the estimated values by:

  - Substantiating estimates by using real data for each case

  - Enhancing the algorithm for calculating the combined values or "bundling"

# Bundling Multiple Storage Applications

## Low-Value Bundling

Total Cumulative Bundle Value

Stacked Applications

$55\% \times V2$

V2

55%

$45\% \times V1$

V1

45%

100%

Availability of Time, Power or Capacity

## High-Value Bundling

Total Cumulative Bundle Value

Overlapping Applications

$35\% \times V2$

V2

35%

$100\% \times V1$

V1

100%

100%

Availability of Time, Power or Capacity
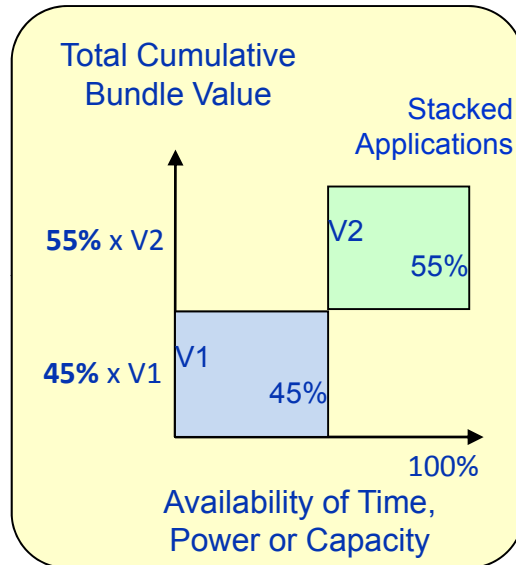
## Stacked Applications

- **Dedicated** Storage Portions (capacity)

- Total Value = 45% V1 + 55% V2
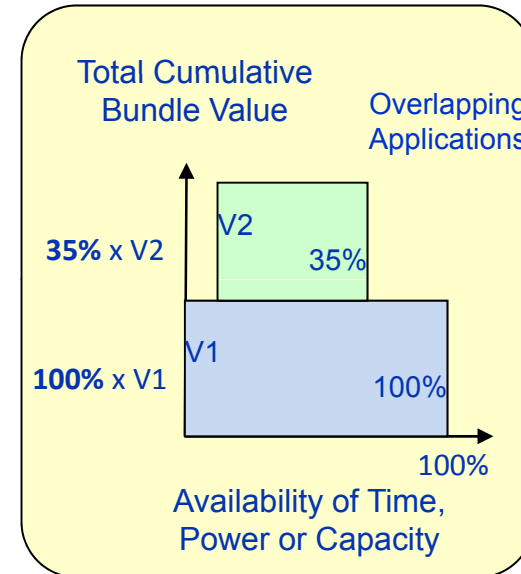
## Overlapping Applications

- **Shared** Storage Portions (capacity)

- Total Value = 100% V1 + 35% V2

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# Total Value of Bundled Applications

The total value of bundled applications is the sum of the "utilized" or realizable values of each application

**Total Value** = 100% x Value 1      First (top Priority) application

        + $UF_2$ x Value 2      second application

        + $UF_3$ x Value 3      third application

        + $UF_4$ x Value 4      fourth application

        + …

**UF** = Utilization Factor = portion of each application value that can be realized in the bundle of applications

# Calculating Utilization Factors

DNV KEMA developed a process to quantify utilization factors (UF) for bundled applications.

Combined Benefit  = Bundle Benefit + UF x Benefit of Next Application

$$UF = \frac{\text{Value of a storage application in a bundle}}{\text{Value of the application by itself (no sharing of storage capacity)}}$$

Previous Higher Priority Application(s)

Storage Availability

Next ($N^{th}$) Application

Peak Time Compatibility

Utilization Factor Algorithm

$UF_N$
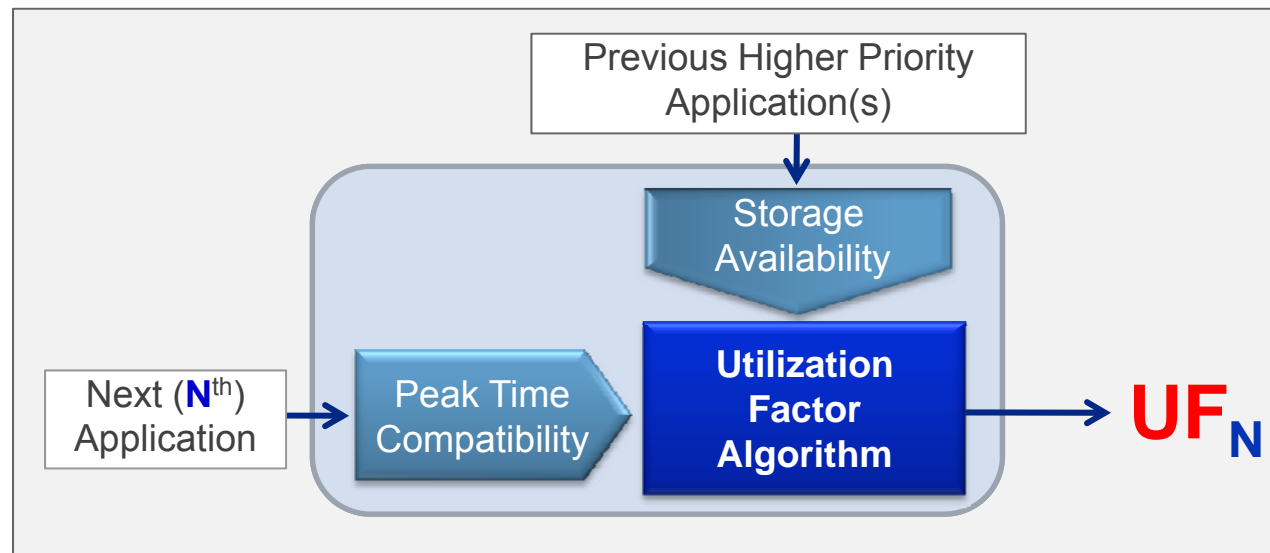
# Substantiated Utilization Factors (UF)

Following are four Bundling cases for which utilization factors have
been calculated using real data from utility (loading), PJM
(regulation) and NREL (PV output)

Range

T&D deferral  (V1) + Area Regulation (V2) =      V1+ (85% - 98%) V2

Retail Time of Use + Area Regulation =      V1+ (70% - 72%) V2

Solar Firming +  Area Regulation =      V1+ (50% - 60%) V2

Solar  Energy Time Shift + Area Regulation =    V1+ (35% - 55%) V2

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# Challenges at Distribution Level that Storage can address

| Issues | Problems | Storage Solutions |
|---|---|---|
| **Distributed Renewables** | • Voltage fluctuations<br>• Harmonics<br>• Non-coincident production<br>• Backfeed<br>• Production variability<br>• Loss of equipment life (due to above) | • Volt / Var injection<br>• Volt / Var injection<br>• Energy time shifting<br>• Energy time shifting<br>• Firming<br>• Improve system control (using above methods) |
| | | |
| **Asset Management** | • Upgrade or capacity needed<br>• Slow equipment deployment / approval<br>• Uncertainty in amount of investment needed<br>• Low asset utilization | • Temporary capacity<br>• Modular / transportable<br>• Cheaper, smaller increments of re-usable capacity<br>• Peak load shifting |
| | | |
| **Power Outages** | • Lost revenue<br>• Contract / regulatory penalties<br>• Slow restoration process, e.g., cold load pick-up<br>• Customer Outage costs & inconvenience | • Utility service during Outage<br>• Utility service during Outage<br>• Facilitate restoration via Load Control<br>• Service during Outages, quick to bring on-line |
| | | |
| **Electric Vehicle Integration** | • Equipment loss of life, e.g., transf. cool-down<br>• Equipment overloading & resulting Impacts | • Relieves equipment loading<br>• Increased capacity |
| | | |

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# Energy Storage Options / Locations / Formats

## Energy Storage Types & Cost

- Lead Acid
- Flow Batteries
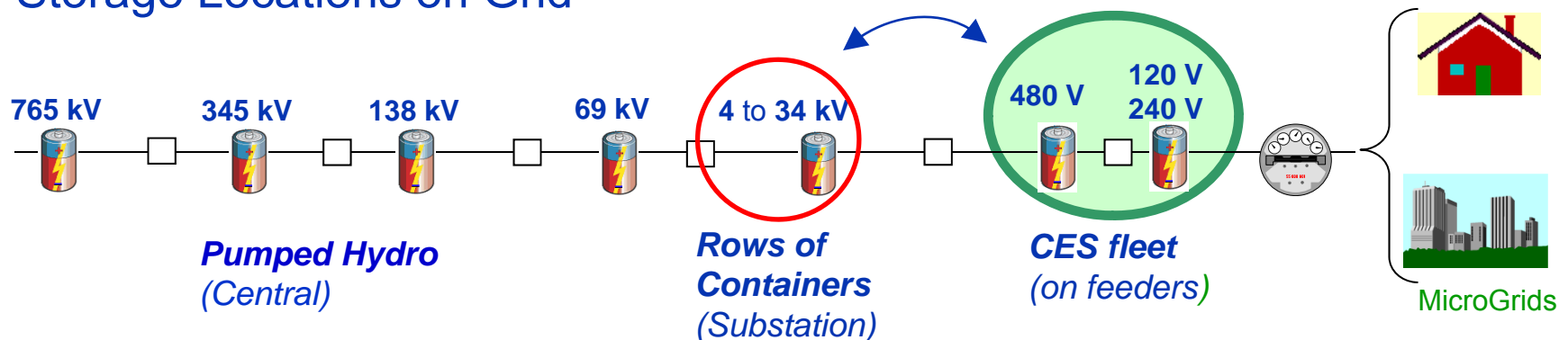- Li-ion group
- NaS
- NaNiCl
- …

## Solution Providers

- GE
- ABB
- S&C Electric
- Demand Energy
- …

## Plug-n-Play Packages

- CES
- Shipping Containers
- Mobile Trailers
- …

## Storage Locations on Grid



765 kV 　　 345 kV 　　 138 kV 　　 69 kV 　　 4 to 34 kV 　　 480 V 　 120 V 240 V

**Pumped Hydro** *(Central)*　　**Rows of Containers** *(Substation)*　　**CES fleet** *(on feeders)*　　MicroGrids

# Modeling Flow

**User Interface**
*Input profile assumptions*

**Multiple Scenarios**

**Distribution Circuit Model(s)**
*Circuit assumptions*

**Storage Controls**

**Model Data Processing**
*Storage project assumptions*

**Charts / Conclusion**

*Select*

*Run*

*Analyze*

**Inputs**
Load profiles
EV / No EV
PV / No PV (customer vs. util)
Storage / No Storage
Storage Control Priority
Reliability Event
Etc.

**Engineering Outputs**
kW Delta (time)
Energy ∫kW
Voltage Levels (time)
Harmonics
'Equipment' Usage (#)
Storage Usage (# cycles)
Etc.

**Translation**
Capacity
Energy Shifted
Energy Savings
Power Quality Δ
Reliability Δ
Asset lifetime
Storage lifetime
Etc.

**Financial Outputs**
Storage Costs
Storage Benefits
  Avoided Costs
  Earnings
Alternative Benefits
Asset loss of life
Deferral values
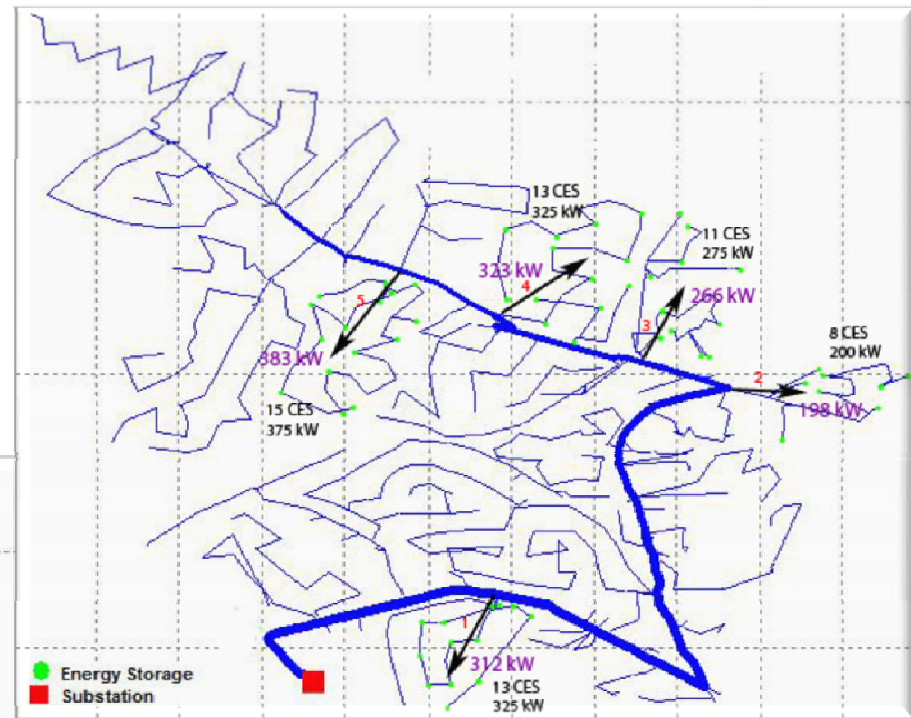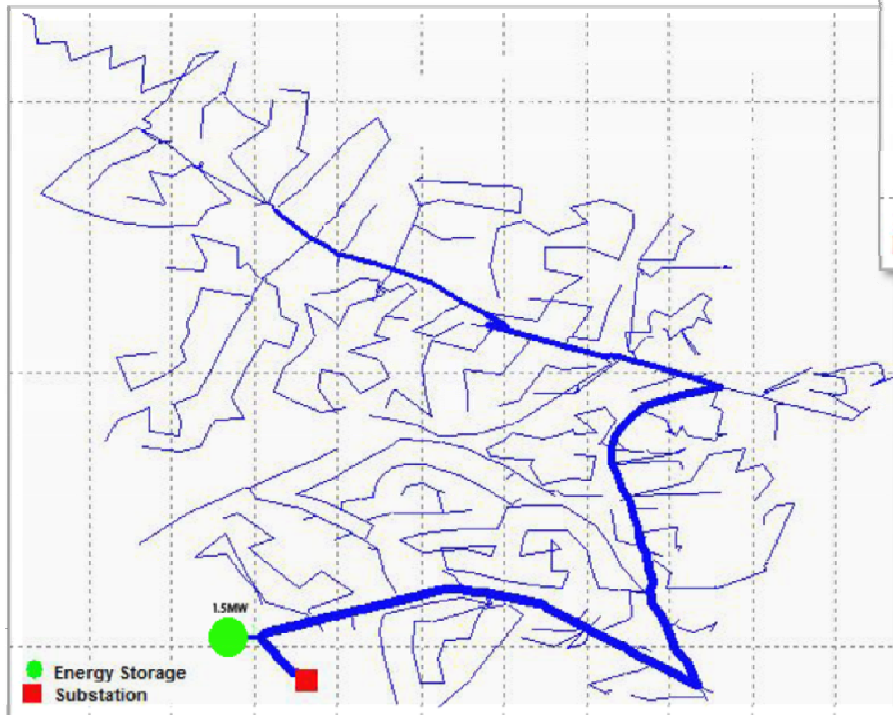Etc.

# Distributed Storage: Multiple versus a Single Unit

**Substation versus edge of Grid**

- Difference in performance
- Difference in benefits
- Difference in costs



| Site | Peak Demand (kW) | Peak Demand (kVA) | # of Devices | Capacity (kW) |
|------|------------------|-------------------|--------------|---------------|
| 1 | 312 | 386 | 13 | 325 |
| 2 | 198 | 244 | 8 | 200 |
| 3 | 266 | 320 | 11 | 275 |
| 4 | 323 | 399 | 13 | 325 |
| 5 | 383 | 474 | 15 | 375 |

# Assessing Storage Locations

## **Meeting Circuit Needs**

- Storage solution tailored to circuit
- Evaluates multiple options
- Allows for identification of best value options

| Site | Peak Demand (kW) | Peak Demand (kVA) |
|------|------------------|-------------------|
| 1 | 4,555 | 5,079 |
| 2 | 3,716 | 3,716 |
| 3 | 2,876 | 3,031 |
| 4 | 1,853 | 1,868 |
| 5 | 992 | 1,231 |
| 6 | 453 | 576 |
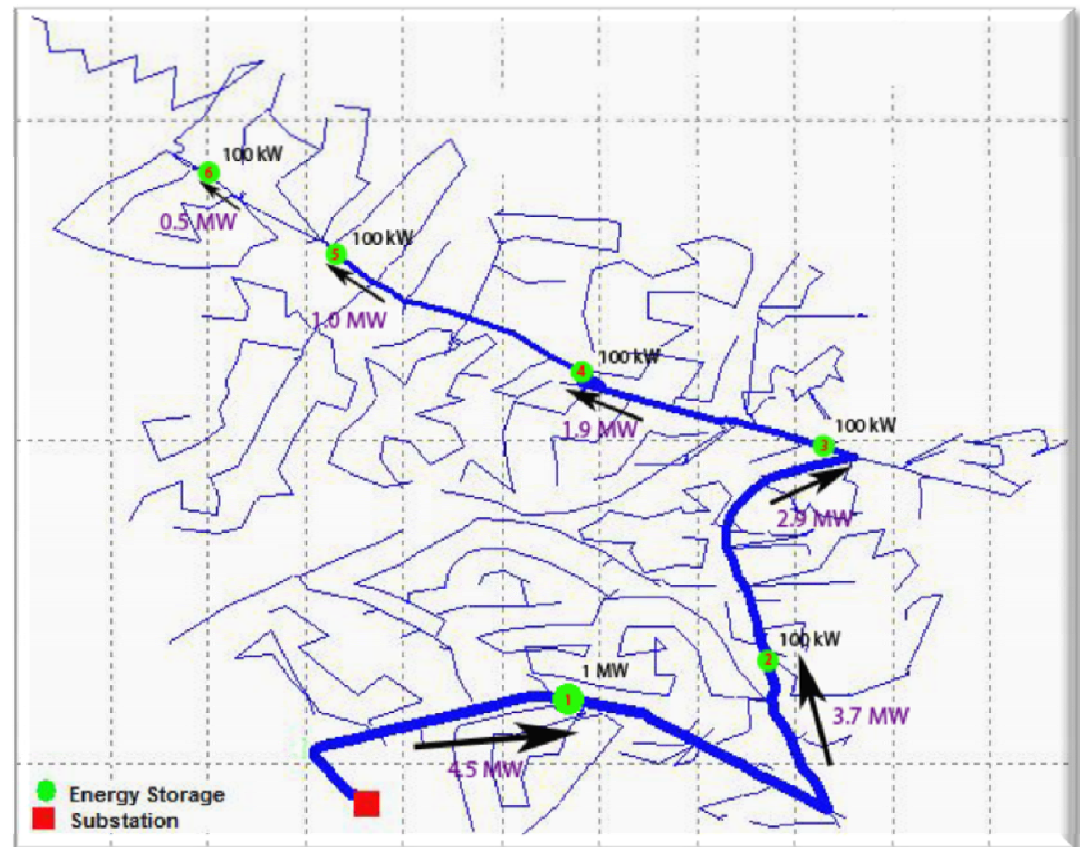
# Bundling & Controls

- Bundling applications allows you to achieve the maximum benefit for an investment

- Controls are key to efficient bundling
  - Does the battery have enough energy to serve an application when its needed?
  - Are applications compatible, and if not, which application has priority?
  - Does adding an application require additional capacity/energy and if so, is it cost effective for the incremental investment needed?

- Yet, controls must be robust and cost-effective to implement
  - Can the current communications infrastructure support the control scheme and if not, is the incremental investment worth it?
  - Are the controls simple enough to execute over all system conditions, but sophisticated enough to maximize value?

- DNV KEMA's analysis is flexible with regarding control schemes
  - The modeling analysis can incorporate multiple types of controls
  - The team is currently analyzing rule-based approaches and comparing these to 'theoretical', optimal schemes  to gauge value
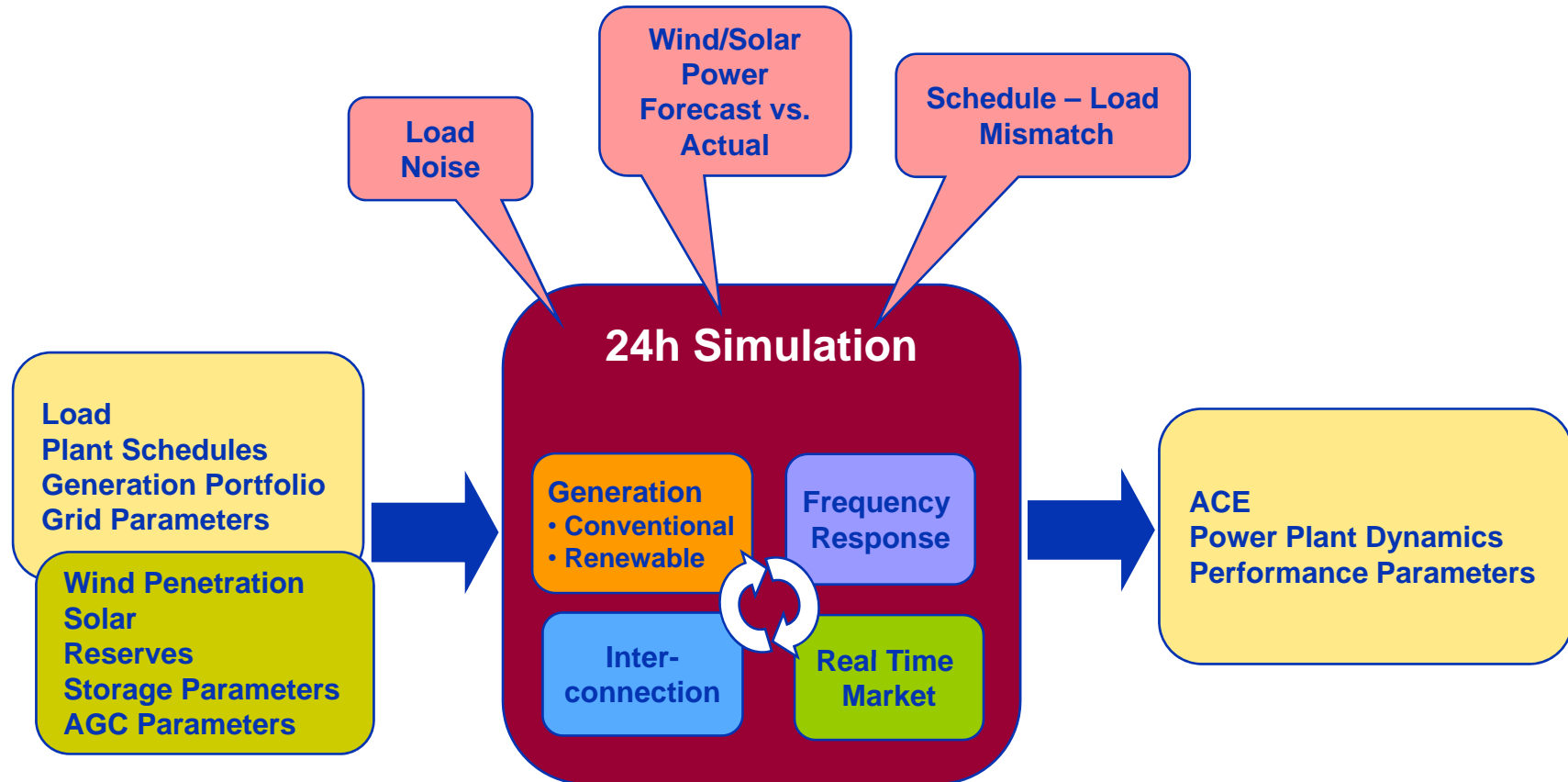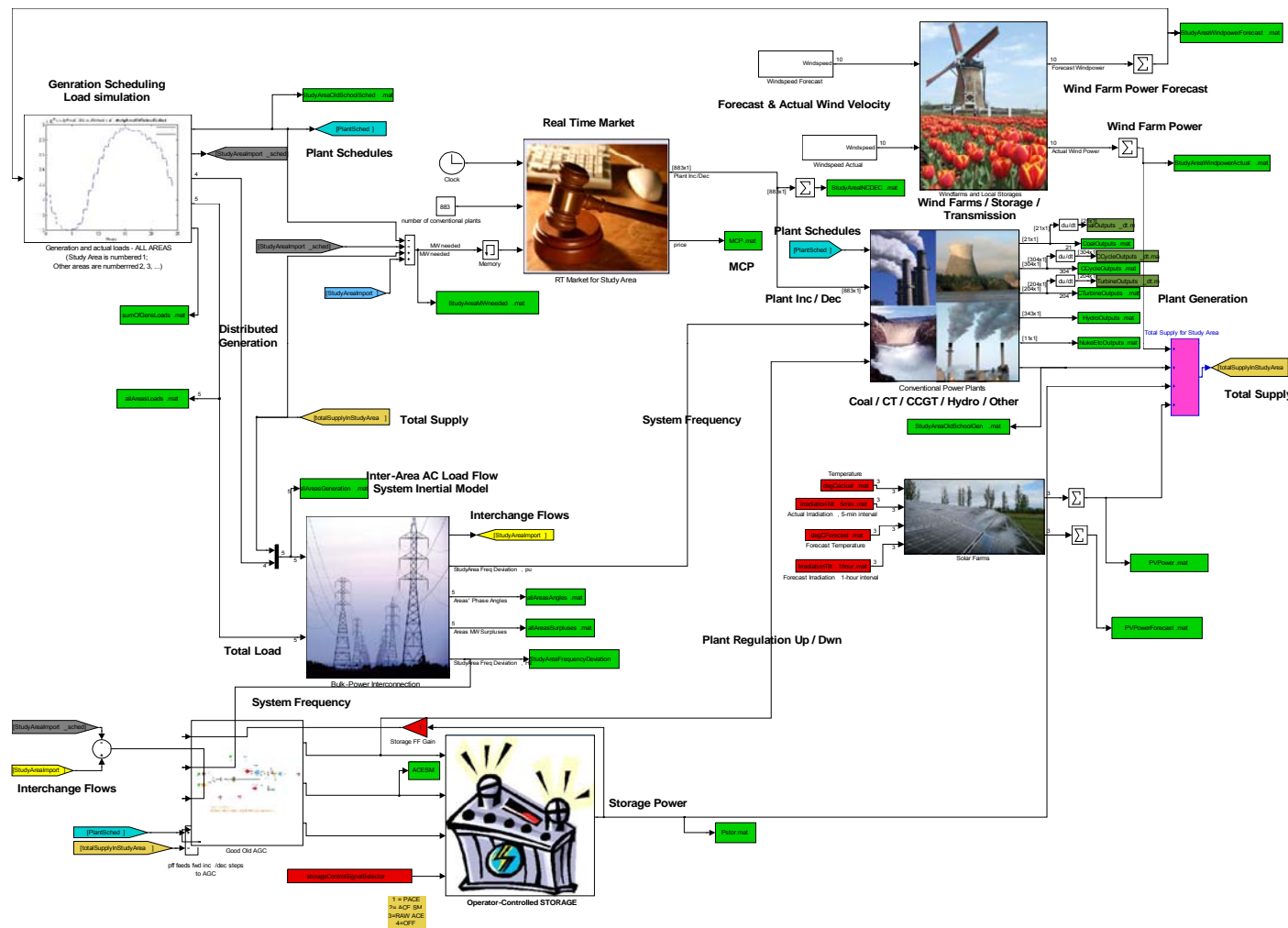
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# KEMA Renewable Energy Integration and Modeling Tool

- Developed by KEMA in Europe and the US

- Simulates Real Time Power System Dynamics

- Quantifies Impact of Variable Power Sources on System Operation

- Capabilities:
  - Effect on system dynamic when adding wind and solar to the generation mix
  - Assess opportunities for storage in regulation
  - Compare operation control strategies
  - Investigate integrated approach for wind, solar and storage

# The Simulation Concept



Load Noise

Wind/Solar Power Forecast vs. Actual

Schedule – Load Mismatch

**24h Simulation**

Load
Plant Schedules
Generation Portfolio
Grid Parameters

Wind Penetration
Solar
Reserves
Storage Parameters
AGC Parameters

Generation
• Conventional
• Renewable

Frequency Response

Inter-connection

Real Time Market

ACE
Power Plant Dynamics
Performance Parameters

# Graphical User Interface



Simulink GUI running MATLAB code

New model is scalable and fast

Typical simulation span: midnight to midnight

# Features of our Simulation Model

- Time Varying Generation and Loads

- Balancing Market for Electricity

- Dynamics of Conventional Power Plants

- Automatic Generation Control

- Bulk Power Interconnection Dynamics

- Wind Farms

- Photo Voltaic

- Storage (Operator Controlled and Local)

- Emissions (CO2, NOx)

# Areas of focus for Tool

- **Continue to Explore "Fast Regulation Services" Possibilities**

- **Protocols for Renewable Operation**
  - Example: partial shut-down in anticipation of fall-off
  - Matching wind farm peak capacity plus storage to transmission limits

- **Evaluate Impact of Changes in Balancing Market**
  - Different look-ahead schemes
  - More Frequent Operation

- **Explore Demand Side Impacts**

- **Model Actual Plant Regulation Activity**

- **Model Emissions Impact of Decreased Plant Regulation**

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# Use Example of Use Case - Distributed Storage

- How will tools be applied to the specific examples
  - In the suite of DNV KEMA Tools, will utilize ES-Select and draw upon Distribution Valuation model as required

- Why ES-Select
  - Incorporates cost and comparison of all potential storage technologies
  - Capable of bundling additional applications into the analysis in order to maximize the benefits that are used in the cost effectiveness evaluation

- Example of Use Case – Deferral of Distribution Upgrades
  - Primary Application – Deferral
  - Secondary applications
    - Reliability
    - Peak Shaving
    - Volt-Var Control

# Use Example of Use Case - Distributed Storage

- **Use Case Development – Model to Cost effectiveness**
  - Benefits and Cost will be defined through ES-Select
  - Comparison of alternative approaches will flow through financial modeling of the applications

- **Additional areas of analysis**
  - Utilization of Distribution Valuation model
    - Defines distributed storage
    - Substation vs. Edge of the Grid
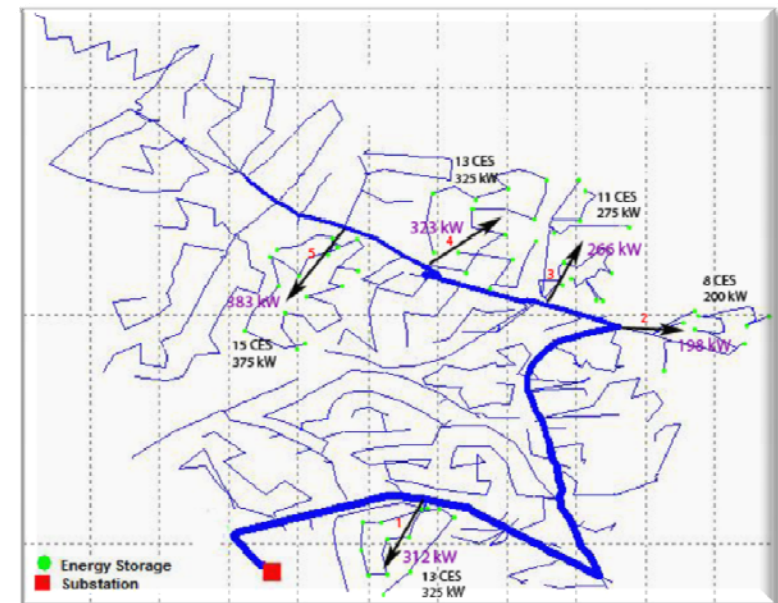
# Use Example of Use Case – Ancillary Services

- **As applications transition to Wholesale – Bulk Applications, DNV KEMA will Utilize additional tools**

- **Utilization of KERMIT Model**
  - In the suite of DNV KEMA Tools, will utilize KERMIT Model to provide analysis of the primary application
    - Model is already calibrated for the CAISO system
    - Tap into ES-Select tools to examine the potential technologies that can be utilized in the analysis
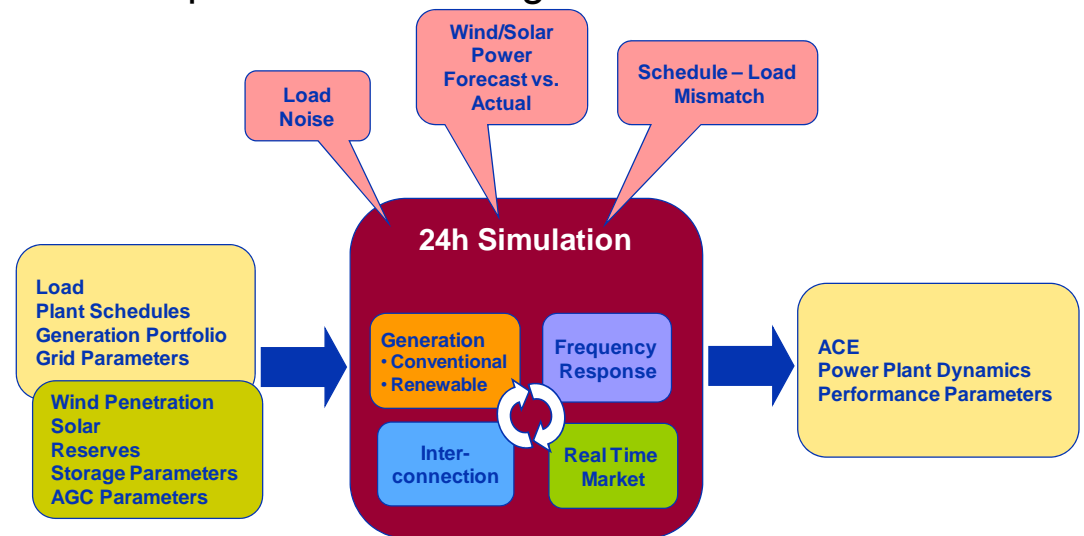
# Use Example of Use Case – Ancillary Services

- **Bundling of applications with Ancillary Services?**

  - In Use Case Analysis, where possible, potential bundling will be examined in the cost effectiveness approach